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THE ADVANTAGES OF A HIGH PRESSURE HOUSING IN A HERMETIC COMPRESSOR

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ABSTRACT

High pressure housings have successfully been applied to mechanisms such as the hermetic rotary compressor. These designs are generally rigid mounted and of a direct suction concept. The rotary compressor, for example, has demonstrated that it has a high level of reliability. With improved manufacturing techniques, it has also produced very high efficiencies.

The capital investment to produce the required manufacturing techniques is relatively high compared to the traditional reciprocating design. The rotary design is limited to sizes used in the small unitary applications; the reliability in split systems, for example, is unproven.

The high pressure housing with direct suction and rigid mount construction has not yet been applied to a reciprocating hermetic compressor. More attention has been given by the compressor designer in how to improve the conventional low pressure reciprocating hermetic rather than taking advantage of features which made the rotary successful.

This paper describes the use of an improved reciprocating hermetic design as applied to a high pressure housing. This design has both a direct suction and rigid mount construction.

INTRODUCTION

The reciprocating mechanism offers a decided advantage in that it has geometries which are familiar to other industries, such as the automotive and small gasoline engine. The technologies to efficiently mass produce the components are rather advanced and refined.

Newer compressor technologies, such as the rotary and scroll, require the development of more refined technologies in order to mass produce them. These new technologies can tend to be rather expensive to develop and to mass produce components. The cost to bring these new, high efficient designs to the marketplace must ultimately be paid by the consumer.

Do these new technologies have a wide base of application or are they limited, for example, to small unitary applications such as the rotary? Further, will these new technologies have the same reliability as achieved by the reciprocating mechanism that has been applied to a wide range of applications?

This paper looks at the advancement of the reciprocating hermetic compressor when it is applied to a high pressure housing with both direct suction and rigid mount construction.

What happens when the features which have made the rotary compressor successful are applied to a reciprocating mechanism? The results of this is a mechanism which has a wide range of application, the efficiency to compete with a scroll and the reliability to rival the rotary.

DESIGN CONSIDERATION

When we examine the rotary design, we see a mechanism that is rigid mounted with a direct suction. The improved gas dynamics has reduced the amount of heat transfer and pressure drop on the sensitive suction side of the compressor. It has also eliminated the need for a discharge shockloop and, thus, has improved the flow characteristics on the discharge side as well. The housing is now able to attenuate the discharge pulse which, in the past, could produce an unacceptable driving force from which noise, generated in the condenser and interconnected discharge tubing, proved to be objectionable to the customer.

One shortcoming of the rotary design is that there is no suction valve which acts as a barrier to the suction pulse. The suction accumulator on a rotary is required to do double duty as an accumulator and as a suction muffler. Even with this, the system designer has to be aware of frequencies which can cause "coil buzzing" in the evaporator coil. Tubing length and diameters are critical in order to reduce this phenomenon.

In addition, the system designer must take into consideration the torsional vibration produced by the single-cylinder rotary. System designs usually include added external shockloops, such as "hair pin" configurations. These are added in order to prevent interconnecting tube failures and vibration transmissions from occurring.

The above is generally not a problem on small units where the diameters of the interconnecting tubing is small. The interconnecting tube failures and vibration transmissions are a problem on larger units, but they can be eliminated with a relatively small investment in additional suction and discharge tubing. Large rotary compressors with increased suction and discharge lines may not be as easy to cure.

System contamination on the rotary design can be a disaster since the clearances between the rotating and stationary members are held to close tolerances in order to achieve the high efficiencies. Any foreign debris wedged between the roller and cylinder, for example, can result in a "no start" and an unhappy customer.

The scroll, too, has several inches of continuous sealing surface. Any foreign material would have to pass through this continuous seal and could result in permanent damage.

Split systems, where solder joints and tube cleanliness are not under the control of the original equipment manufacturer, can produce headaches and failed compressors. Large systems, by there very design, are required to be installed in the field. System cleanliness is a concern, and the ability of the mechanism to handle this contamination is more so.

THE NEW DESIGN

The first consideration of the designer is to have a mechanism that is highly reliable and yet economical to produce. The reciprocating design has geometries that are cost effective to produce; and the reliability is well documented with household refrigerators running for 20-30 years not being uncommon.

What the designer wants is a mechanism which has demonstrated over the years that it is not susceptible to foreign materials and can operate under a wide range of conditions.

The enclosed cutaway of the high pressure reciprocating hermetic compressor incorporates these features (see Figure 1). The four coplanar pistons with four equally spaced radial cylinders can be easily machined as two opposed in-line cylinders. They produce an unbalanced force which can be exactly nullified as the tolerance to which the dynamic components can be machined (see Figure 2). There are two counterweights: one located at the intersection of the main and eccentric journals, and one located at the end of the cage journal. These two counterweights resolve any unbalanced force present. In contrast, conventional reciprocating design compressors generally have two or more in-line cylinders. This design can not be completely balanced by adding counterweights. The unbalanced forces could produce undesirable vibrations which could result in internal "housing hits" or failed shockloops.

Please note Figure 3 which illustrates the type of unbalance force produced by a conventional two-cylinder compressor. The polar plot represents the magnitude and direction of unbalanced forces produced with respect to time. The four-cylinder, scotch-yoke design can be completely balanced (see Figure 2). This feature is paramount when considering a rigid mounted design compressor where the unbalanced forces would necessitate the use of elaborate interconnecting suction and discharge tubing problems.

An additional benefit of the above design is the compact package it provides. Compare, for example, this design with that of another four-cylinder design where the cylinders are not coplanar. Referring to Figure 4, please note the difference between the two designs with respect to distance between the main bearing supports. This will allow the designer to take advantage of the close coupled bearings and, thus, reduce the amount of mass in the eccentric journal without compromising the stiffness of the crankshaft. Bearing frictional losses in the eccentric can be optimized as a result of bearing requirements rather than the required structural stiffness.

The four pistons have piston rings which seal between high and low pressures. They do not rely on two highly machined surfaces to form a seal. The required run-in time to achieve steady state performance is minimized. Piston rings are not as susceptible to foreign material and, when seated, are able to compensate for irregularities in the cylinder bore.

The suction gas is delivered through a connecting tube into the yoke cavity and also serves to isolate the internal mechanism from the housing. This greatly reduces the effect of heat transfer from the hot discharge side to the cool suction gas. The suction gas, like the rotary, is directly routed to the compression chamber. Unlike the rotary, this design has a suction valve to minimize the effect of suction gas pulsing.

The newly developed suction valve mounted on top of the piston is inertially assisted in order to provide the optimally timed closing action of the suction valve. Conventional designs generally rely on pressure actuated flapper valves that are forced open and close by gas pressure. During low temperature heat pump conditions, conventional valves often exhibit erratic closing patterns. (Refer to Figure 5 for the calculated valve closure for a conventional reciprocating compressor. Note the erratic closure which may be due to the gas pulsations in the suction cavity overriding the low forcing pressure which normally dictates the suction valve closing.)

The discharge valve provides for minimal flow restriction and is supported by a discharge valve retainer. The valve retainer is able to allow the discharge valve to lift off of the valve seat during abnormal hydraulic-type conditions.

The main bearing is an overhung design that does not necessitate the need for a lower bearing to stabilize the rotor during start-up conditions. During conditions where the housing has abnormal amounts of liquid refrigerant, a bearing emersed in this liquid refrigerant and oil mixture could result in bearing failures.

The internal compressor assembly is hung from the upper housing where it is acoustically isolated from the housing.

The discharge gas is routed through the internal discharge muffler chambers before it is eventually exhausted into the housing. Since the cylinder heads only act as a muffler cover, they do not require a perfect seal; therefore, no cylinder head gasket is required. This has long been a problem with conventional compressors since cylinder head gaskets can rupture during abnormally high slug conditions and result in a failed compressor.

Another interesting feature of a high pressure housing, with respect to reliability, is the fact that even when the compressor is pulling the suction side into a vacuum, the electrical terminals are not exposed to this vacuum condition. Terminal arching usually occurs during this condition and this failure mode is eliminated by the high pressure housing.

When we, again, refer to Figure 1 and analyze the gas flow pattern of the high pressure reciprocating hermetic compressor, we find that the gas flow pattern is similar to the rotary or scroll. The gas flow never reverses direction from inlet to exit like a conventional compressor. The heat transfer and pressure losses are minimized.

THE MECHANISM

The four pistons, which are really two mutually perpendicularly opposed paired piston yoke assemblies, offer a decided advantage when converting a rotating motion into a reciprocating motion. First, they do not incorporate the need for a wrist pin and a connecting rod. From a reliability viewpoint, this has traditionally been a potential failure mode for conventional reciprocating compressors at high compression ratios. Many low temperature compressors have difficulty with piston pin boss failures. Second, the side wall forces are greatly reduced since there is no connecting rod pushing on the piston at an angle. This both improves efficiency and reduces piston skirt wear.

The reliability of the scotch yoke mechanism has been documented at adverse conditions and at various speeds. Automotive compressor designs have incorporated this four cylinder scotch yoke concept with a remarkable high reliability. They have been tested at speeds in excess of 7,000 rpm's for prolonged periods. It is believed that this design would be successful as applied to a variable speed applications, which appear to be on the horizon for our industry. Since this design utilizes the inertially assisted closing of the suction valve and is optimally balanced, variable speed should not be a factor.

LUBRICATION SYSTEM

The lubrication system is simple and, therefore, foolproof. The centrifugal oil pump delivers oil through the crankshaft to the main, eccentric and outboard bearings. Since the eccentric is positioned entirely in the low pressure gas, the lubrication system is able to take advantage of the pressure difference across the eccentric bearing. As the pressure difference produced by the compression ratio increases, the oil flow through the bearing increases. This self-correcting feature ensures that there is an adequate amount of oil present during high load conditions.

EFFICIENCY IMPROVEMENT - AN OVERVIEW

This reciprocating hermetic compressor design has been optimized for size, balance and efficiency in order to be implemented into a high pressure housing with a rigid mount construction. A high pressure housing with rigid mount construction has always been thought of as unique to a rotary application. Interesting enough, this offers some features beyond what the present rotary compressor can produce.

Suction and discharge pulsations are minimized while balance is perfect.

When comparing to a conventional low pressure housing it can be seen that there is still another feature not discussed - the housing surface itself is now part of the condenser rather than the evaporator. The system designer should be able to take advantage of the additional condenser area.

Figure 6 compares the efficiency of a present day scroll and rotary with both the conventional reciprocating low pressure housing hermetic and the new high pressure reciprocating hermetic discussed above. It can be seen that the high pressure reciprocating hermetic is comparable to the scroll and rotary and is significantly better than the conventional hermetic compressor.

RELIABILITY - AN OVERVIEW

During off cycle conditions, liquid refrigerant can migrate to the compressor housing. Even with crankcase heaters, circumstances can occur which will overpower the crankcase heaters. In a conventional low pressure reciprocating compressor, when the compressor starts up, the housing pressure is instantly reduced, which can result in a violent eruption of liquid refrigerant and oil being driven into the compressor cylinder. Severe damage can result from this. During the off cycle, all the liquid refrigerant trapped in the housing has to pass through the piston and valve assembly of the compressor.

In the high pressure reciprocating hermetic, under the same conditions as above, the liquid is already on the high pressure side of the housing. When the compressor starts, the pressure in the housing increases. This tends to keep the liquid refrigerant from pumping the oil out of the compressor. During a cold start, the refrigerant is driven out as a function of both the motor heat and the heat of compression increasing. The increase in housing temperature is generally associated with compressor load increases. At start-up conditions, the bearing loads are light until the system can come up to pressure. This happens after the refrigerant is driven out of the housing by the housing temperature surpassing the saturation temperature of the housing. This factor, as in a rotary application, tends to limit system pressure until the refrigerant can be driven out of the compressor housing.

SUMMARY

High pressure housings, as applied to a hermetic compressor, is not new. Rotary designs using the high pressure housing concept have been successfully applied in our industry for years. Even high pressure housings which utilize the scroll concept have been applied. The conventional reciprocating hermetic compressor has never truly been looked at in terms of a high pressure housing. This may be in part due to the fact that most conventional designs do not incorporate the necessary optimum features to successfully allow them to be used in a high pressure housing with direct suction and rigid mount construction.

The new reciprocating design discussed above has been optimized in order to take advantage of the features that have made the rotary successful with respect to reliability and efficiency.

What has been discovered is that the reciprocating mechanism can bring some interesting advantages to the high pressure housing concept. These advantages offer more than what the conventional rotary can provide. The new reciprocating design does not appear to have the limitation of size associated with the rotary.

The arrival of the scroll promises to out perform the conventional reciprocating compressor. The difference between the two designs is not as great as it once was. Today's new low pressure reciprocating compressors are pushing the efficiency envelope outward.

The technology to mass produce the rotary and scroll is not inexpensive. This cost will ultimately have to be paid by the consumer. The range that this new technology can successfully be applied to is not certain.

This new high pressure hermetic reciprocating design offers efficiencies that will compete with the scroll and rotary and yet utilize the same technologies that have been used for years to produce the conventional reciprocating compressors.

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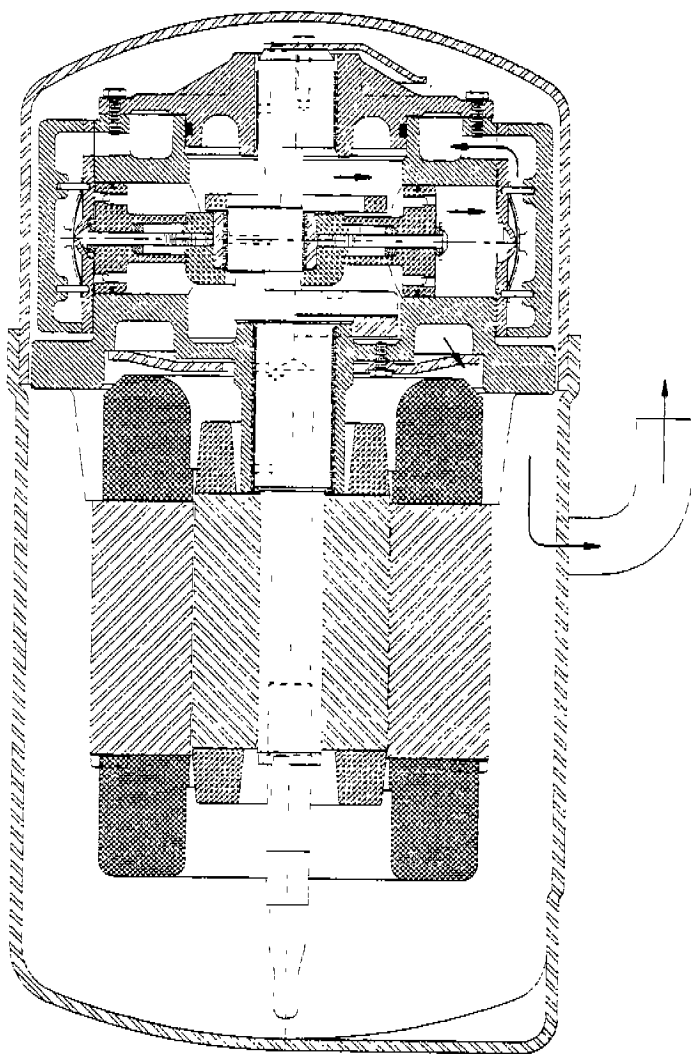
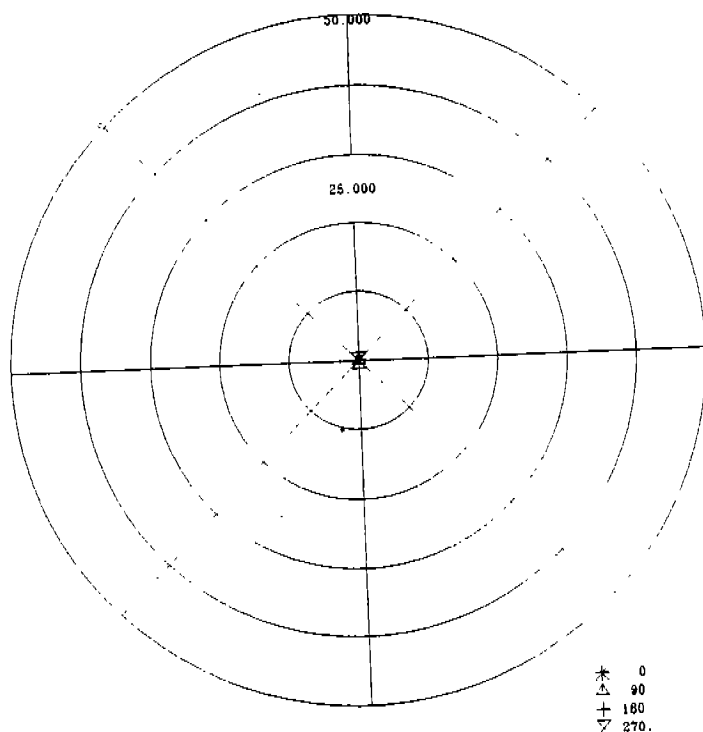
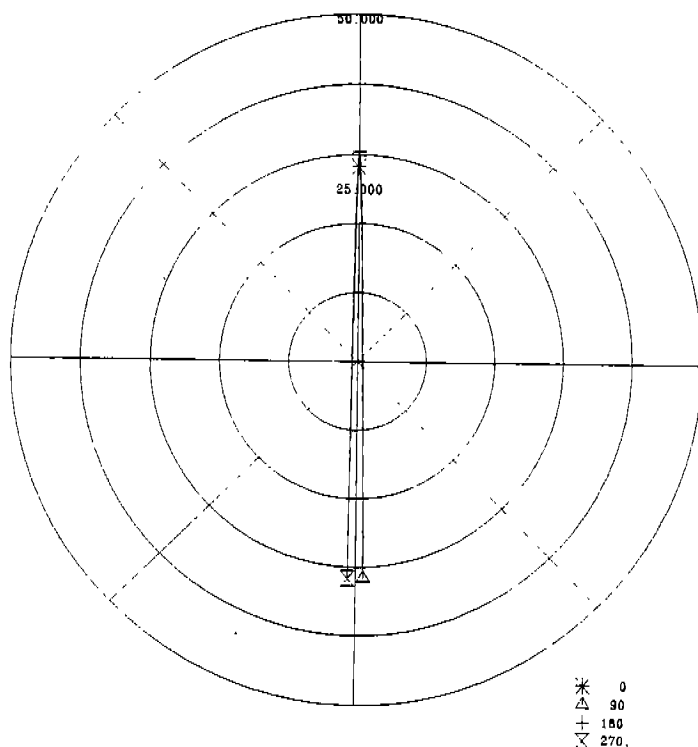


FIGURE 1
NEW DESIGN
HIGH PRESSURE HOUSING RECIPROCATING HERMETIC
FOUR-CYLINDER DESIGN



POLAR PLOT OF TOTAL UNBALANCED FORCES ACTING ON CASTING

Figure 2. 4 Cylinder Scotch-Yoke Optimally Balanced New Design Reciprocating Compressor



POLAR PLOT OF TOTAL UNBALANCED FORCES ACTING ON CASTING

Figure 3. In Line 2 Cylinder Slider-Crank Optimally Balanced

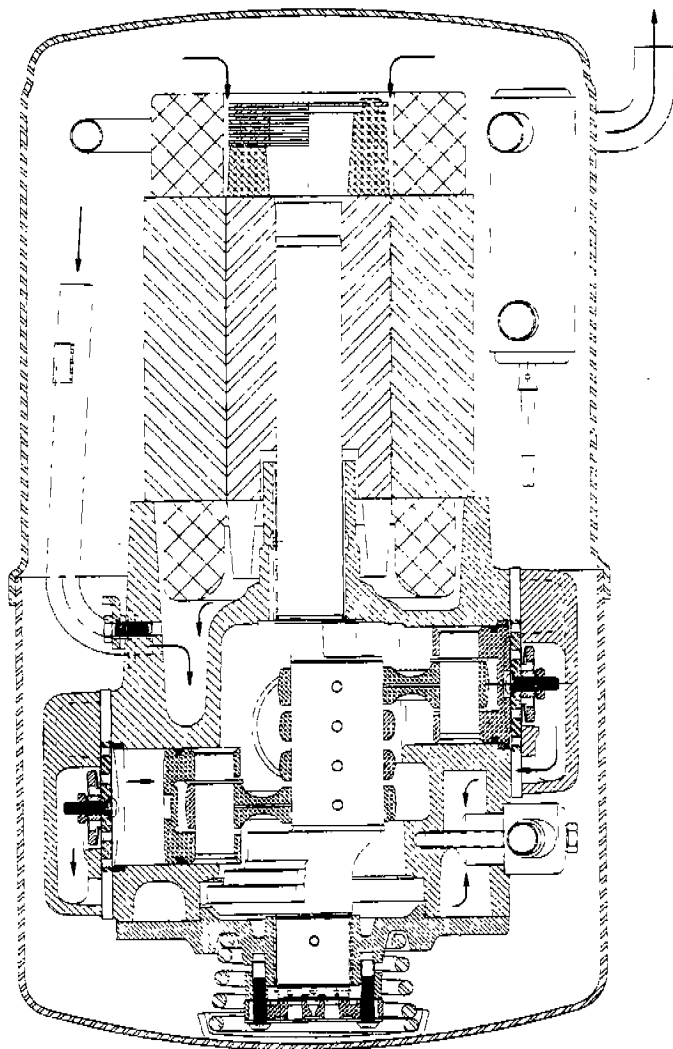
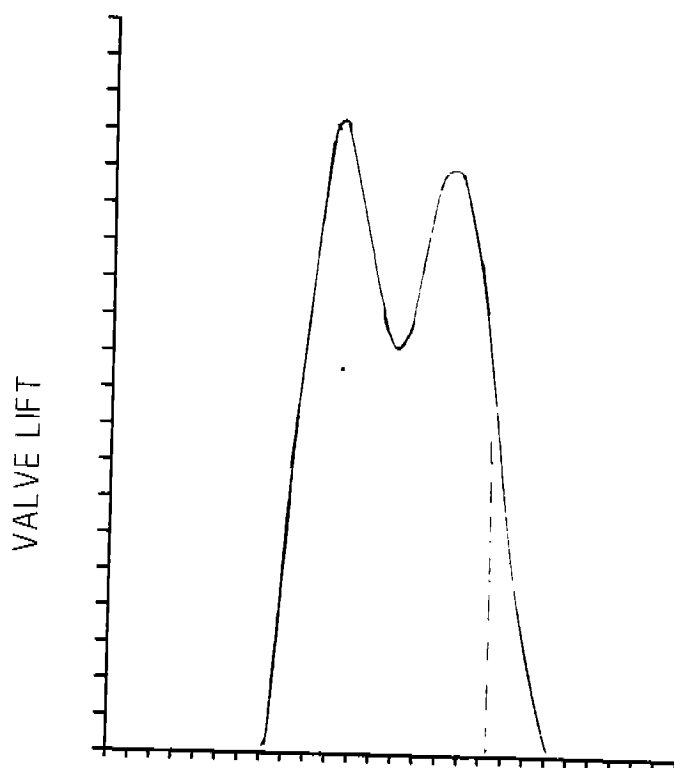


FIGURE 4
CONVENTIONAL RECIPROCATING LOW PRESSURE COMPRESSOR
FOUR-CYLINDER DESIGN



CRANKSHAFT POSITION (DEG. A.T.C.)
Calculated Valve Closure For a Conventional
Reciprocating Compressor

FIG. 5

